Progress of Construction and Installation of the SPIRAL2 Accelerator

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(on behalf of the SPIRAL2 Teams and Partners)

Abstract

Officially approved in May 2005, the SPIRAL2 project is under construction at GANIL, with the active participation of French laboratories (CEA, CNRS) and international partners. This new facility is composed of a linear accelerator producing deuteron, proton and heavy ion beams in a wide range of energies and intensities, with two dedicated experimental areas in the fields of Neutron for Science (NFS) and very heavy and super heavy element production (S3). In a second step, the facility will also produce rare elements serving a low energy RIB experimental hall, or post-accelerated by means of the existing cyclotron CIME. This paper presents the performances of the main accelerator components, its construction status and the installation process into the SPIRAL2 building.

INTRODUCTION

The SPIRAL2 radioactive ion beam facility at GANIL (Caen-Normandy) has been launched in July 2005, with the participation of many French laboratories (CEA, CNRS) and international partners. Figure 1 describes the project layout. SPIRAL2 complex is built in two phases:

- *Phase one* includes the complete accelerator and two new experimental halls, the Super Separator Spectrometer (S3) and the Neutron-based research area (NFS), all to be installed in a new dedicated building.
- *Phase two* includes the RIB production process and building, the low energy RIB experimental hall (DESIR) and the transfer line connection to the present GANIL facility for RIBs post-acceleration by means of the existing SPIRAL1 cyclotron called CIME.

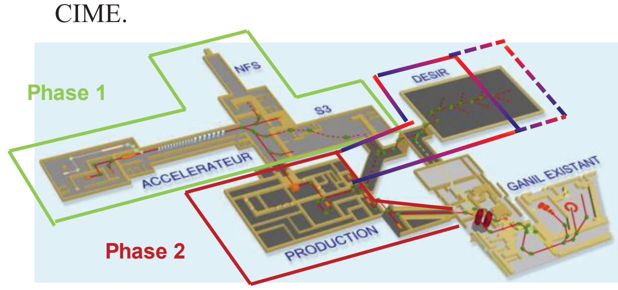

Figure 1 : SPIRAL2 phase 1 and phase 2 layout.

The planning objective of the first phase is to have installed and tested the whole accelerator in order to start the experiments with NFS and S3 in 2014-2015.

Recalled in table 1, the SPIRAL2 accelerated beams will include protons, deuterons, A/q<3 ions, and optionally A/q<6 ions in the future.

Table 1: Beam Specifications

beam	P^+	D^+	ions	ions
Q/A	1	1/2	1/3	1/6
Max. I (mA)	5	5	1	1
Max E (MeV/A)	33	20	14.5	8
beam power (kW)	≤ 165	≤ 200	≤ 44	≤ 48

In the next paragraphs, we will focus essentially on the first phase of the project, providing the status of the main parts of the accelerator, the progress of construction of its building, and some scheduling.

PHASE-1 BUILDING PROGRESS

The key dates of the building construction are:
- Construction permit: October 2010
- Excavation start: January 2011
- Geotechnical controls: May 2011
- Pouring of first concrete: September 2011
- First GANIL intervention: January 2012
- Low energy building block available: November 2012
- Linac Tunnel block made available: December 2012
- Expected building turnover: mid 2014

Figure 2: View of the SPIRAL2 phase-1 building construction (March 2013).

In March 2013, 92% of the concrete was poured (13000 m^3), thanks to 250 000 work hours, and up to 120 workers on site. Figure 2 shows the state of it.

Although the construction of the accelerator building is not completely achieved, the installation of the accelerator itself has started in parallel in November 2012 in order to be able to provide beams as soon as possible. A scheduling and co-activity care is carefully checked between the construction workers and the accelerator teams. The organisation of both the building construction and the accelerator installation favours the low energy end. In the past years the injectors were tested in partner laboratories, and we should be able to resume quickly up this stage. It is plan to first limit ourselves to the RFQ diagnostic plate, with all beam types except deuteron beam. In these limiting conditions, no activation had to be

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feared and faster authorization is expected from the safety authorities, allowing us to start low energy beam tests while the building is not fully received.

ACCELERATOR STATUS

ECR Ion Sources and LEBT

The Spiral2 injector, dedicated to protons, deuterons and heavy ions of q/A>1/3, is mainly composed of two ECR ion sources with their associated LEBT lines, a warm RFQ and the MEBT line connected to the LINAC. As explained in detail in [1], the 18GHz ECR heavy ion source, called Phoenix-V2, and it's LEBT have been installed at LPSC/Grenoble for a few years: many technical and beam tests were successfully performed with expected emittances of 0.25 π.mm.mrad (norm, rms) and about 95% beam transmission (1mA of $^{16}O^{6+}$, 70µA of $^{40}Ar^{12+}$, 2mA of $^{4}He^{2+}$ and more than 20 µA of $^{58}Ni^{19+}$).

The Low Energy Beam Line LEBT1 was dismounted and transported from Grenoble to GANIL in July 2012, and is presently under installation underground in the SPIRAL2 building, as can be seen on Figure 3.

In parallel the Phoenix-V2 ECR source itself is maintained at LPSC/Grenoble in order to pursue intensive metallic ion beam tests, using another available beam line. An intensity of 15 µA $^{40}Ca^{16+}$ is presently reached. (calcium consumption ranging from 1 to 2 mg/h).

A development progam is also conducted to increase the volume of the plasma chamber and improve the magnetic configuration of the Phoenix source. (LPSC, GANIL and IPN/Lyon work).

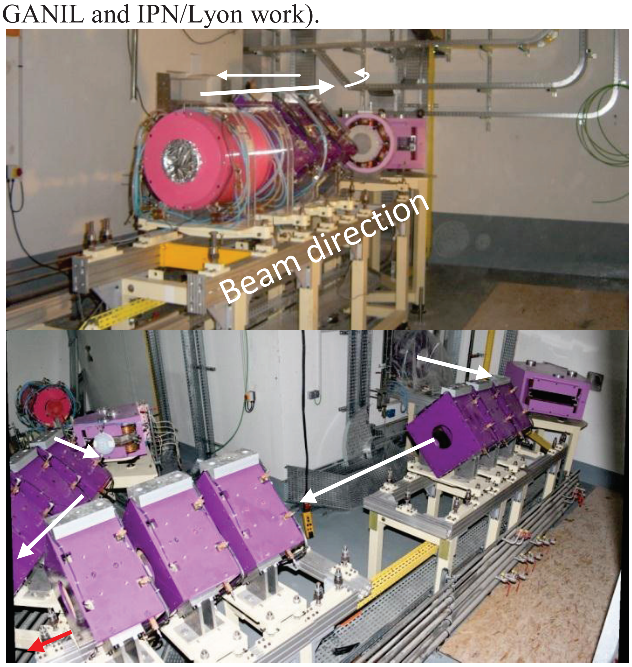

Figure 3: LEBT1 and LEBT2 installation.

In parallel, the light deuteron/proton ECR source, its LEBT2 line and the common LEBTc line were fully tested with beams in 2009-2012 at IRFU/SACLAY. In particular, beam behaviour using the slow chopper developed by INFN/Catania, and beam emittances at the RFQ matching point were measured (see [1] for details).

The 5-mA CW deuteron beam has been measured with an emittance of 0.13 π.mm.mrad (rms, norm.). Up to 12 mA at the line end has been measured.

The 88 MHz RFQ, MEBT and Diagnostic-Plate

Developed by IRFU/Saclay, the RFQ is a 4-vane, 88MHz, 5-meter copper cavity ensuring bunching and acceleration of the continuous beam up to 0.73 MeV/u.

All the RFQ parts are now constructed, but not yet assembled and validated. The main issue observed during the tests of the first 1m-segment concerned serious vacuum leaks. This problem is now solved thanks to a careful preparation of vacuum seals and surface copper roughness. The vanes tips positions were measured successfully on place for the first segment.

In parallel, the integration system of the RFQ segments is ready, and the cooling-tuning system call for tender launched.

Figure 4 : RFQ end-vane details.

The magnets, supports, vacuum pipes of the 8-meter 0.73 MeV/A MEBT line are ready to be installed. The first re-buncher was successfully tested at GANIL with the whole RF, LLRF, PLCs and EPICS/Xal related systems, while the fast chopper is under finalisation.

For the beam RFQ commissioning, a diagnostic plate will be installed after the 1st re-buncher of the MEBT. It is under mechanical assembly and technical tests at IPHC/Strasbourg.

SPIRAL2 Linac

The super-conducting linac is composed of two types of QWR cavities, beta=0.07 and 0.12 operating at 88 MHz.

All cavities, four A type of cryomodules and one B type have been validated, see table 2.

Table 2: cryomodules performances.

	Unit	Specs	CMA4	CMA6	CMA7	CMA2
Max. acc. Gradient	MV/m	>6.5	8.8	8.3	9	9.1
Total losses @4K	W	<20.5	20.8	11.4	11.8	13.2
Static losses @4K	W		6.5	4	4.1	3.2
Pressure sensitivity	Hz/mbar	<5	-1.58	-1.32	-1.45	-1.31
Beam vacuum leaks	mbar.l/s	<5e-10	9.50E-10	< 1e-10	< 1e-10	< 1e-10
Cavity alignment	mm	◎ 1.3	0.52	0.4	0.48	1.46
	Unit	**Specs**	**CMB1**		**CMB2**	
Max. acc. Gradient	MV/m	> 6.5	>8.0	>8.0	>8.0	>8.0
Total losses @4K	W	< 36.0	29.5		32	
Pressure sensitivity	Hz/mbar	< 8.0	5.7	5.1	5.3	5
Beam vacuum	mbar	< 5.0e-7	< 6.0e-8		< 6.0e-8	
Beam vacuum leaks	mbar.l/s	< 5e-10	< 1e-10		< 1e-10	
Cavity alignment	mm	◎ 1.2	0.16	0.34	0.88	2.54

The main past difficulties were related to pollution problem and are explained in detail in [2] *(This conference)*. The availability of the last cryomodules is expected mid 2014.

SPIRAL2 HEBT

The *HEBT lines* are now completely defined, with all dipoles constructed and being measured (Figure 5), while qpoles and steerers are under construction and the 200 kW beam dump call for tender achieved (Figure 6).

Figure 5 : Field measurements of HEBT dipole magnets.

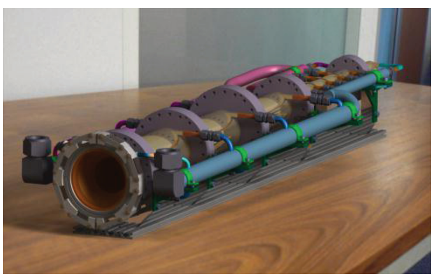

Figure 6 : Sketch of the 200 kW HEBT beam dump.

Specific calculations had to be performed to confirm that the heaviest elements fixation system, including the HEBT magnets, resist to a serious earthquake, avoiding any “missile” effect on the building walls and ground.

In order to limit possible activation induced by deuteron/proton, the choice was made to build the long vacuum pipes in aluminium, and diagnostic boxes in stainless steel, with slightly bigger internal diameter.

DIAGNOSTICS

The complete series of 50 semi-interceptive multi-wire profile monitors and 5 non interceptive monitors (residual gaz ionization) and their electronics, developed at GANIL, are under construction, while LEBT/MEBT Emittance-meters are fully operational.

BPM capacitive probes to be buried into the Linac quadrupoles have been designed by IPN/Orsay. They are presently assembled in the warm section, in the Saclay clean room.

The survey of the beam intensity and the energy, is ensured by several ACCT/DCCT devices, and a ToF system installed at the exit of the Linac. Several Faraday cups, developed by GANIL are already operational.

The complete set of BLM scintillator detectors associated with photo-multipliers are presently developed by IFIN-HH/Bucarest: they will be disposed along the Linac and the HEBT lines in order to deliver a “beam stop” signal in case of excessive beam losses.

AMPLIFIERS

Recent RF system progress concerns the solid state amplifiers. First 2.5 kW, 5 kW, 10 kW and 19 kW units have been commissioned and fit the project requirements. More detail can be found in [3] *(this conference)*.

Command/Control and PLCs

PLCs are based on Siemens S7 serial (S7 1200-300-400 series) for the controls of Cryogenic, beam Interlock, run permit system, Vacuum, ions source, and some safety systems. The high level applications are made under Epics environment or by industrial Scada system.

The Spiral2 control system is based on the Epics environment. Graphic user interfaces consist of CSS/BOY synoptics or programmed Java applications within a specific Spiral2 framework derived from Open-Xal.

During the Grenoble and Saclay beam tests, vacuum, interlock and ions source controls were successfully used. high level applications were used, validating the ability to beam alignment, optimization and halo suppression.

The remaining developments requires big efforts, ongoing by GANIL and Saclay teams (description tools, archiving system, e-logbook, interfaces with beam diagnostics -losses, time of flight, bunch length…-, RF controls and integration with the Machine Protection System)

CONCLUSION

The installation of the accelerator has started, thanks to the work and motivation of all our partners. A great care is taken to coactivity between the process and building teams. We expect starting the commissioning of low energy sources and lines and RFQ commissioning mid-2014, with the start of the utilities (energy, cooling etc...). A huge effort is ongoing in order to obtain the safety authorisations allowing us to accelerate deuteron beam or inject in the linac before end 2014.

AKNOWLEDGEMENT

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